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Editorial

Micro- and Macro-Dynamics of Open Innovation with a Quadruple-Helix Model

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Abstract: This paper explores how sustainability can be achieved through open innovation in the current 4th industrial revolution. Through a literature and practice review, we identify micro- and macro-dynamics of open innovation in addition to the dynamic roles of industry, government, university, and society. In particular, the industry continuously adopts open platforms to create and maintain ecosystem innovation. The government's role has changed from regulation control toward facilitation. Universities have become proactively engaged in multiple areas, from technology transfer to knowledge co-creation. Societies and customers have started to form new concepts, R&D, and commercialization, resulting in a shared economy. Based on the analysis, we propose a conceptual framework to understand open innovation micro- and macro-dynamics with a quadruple-helix model for social, environmental, economic, cultural, policy, and knowledge sustainability. Furthermore, this provides an overview of the special issue, "Sustainability of Economy, Society, and Environment in the 4th Industrial Revolution", which aims to respond to the 4th industrial revolution in terms of open innovation and cyber-physics from manufacturing to the service industry.

Keywords: sustainability; open innovation; micro dynamics; macro dynamics; quadruple-helix; Innovation ecosystem

1. Introduction

As shown in Figure 1, from the micro-dynamic aspect, open innovation means cyclical dynamics among open innovation, complex adaptive systems, and evolutionary change [1], regarded as open innovation, complex adaptive system, and evolutionary change (OCE) dynamics. To start with, open innovation increases the complexity of target systems, such as firms, sectorial innovation systems, regional innovation systems, or national innovation systems. A complex adaptive system can then be achieved with creative development at the evolutionary change level if the complexity is controlled well.

From the macro-dynamics aspect, open innovation involves cyclical dynamics among market open innovation, closed open innovation, and social open innovation [2,3]. Social open innovation, initiated by social entrepreneurs, refers to creative new combinations and connections between technology and society. Social open innovation is becoming the source of market open innovation, resulting in entrepreneurs and start-ups creating new combinations and connections between technology and the market. Market open innovation gives the seeds to closed open innovation through large firms' merger and acquisition (M&A), partnership, and diverse open innovation

channels. The dynamic balance of these three open innovations motivates the growth of the economy quantitatively and qualitatively.

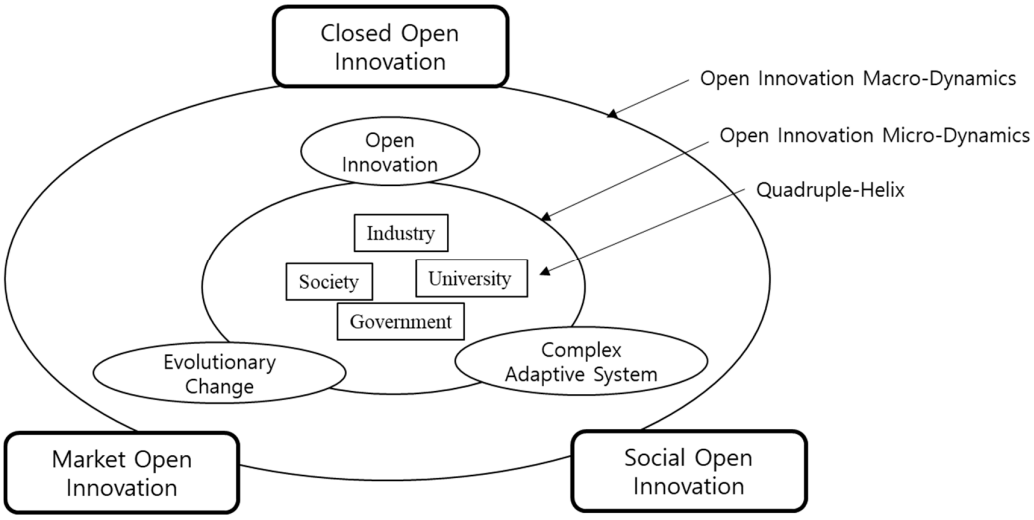

Figure 1. Micro- and macro-dynamics of open innovation with a quadruple-helix model.

Innovation is considered to be an important condition for organizational construction and strategic maintenance, which can enhance the competitive advantage of firms, ensuring sustainability and prosperity. Collaborations and alliances have become a trend in regard to enabling long-term business growth. Open innovation combines internal and external resources to generate new technologies and identify new paths to the market [4]. With open platforms, technological advancement, mobility of highly educated people, and societal engagement, companies can absorb knowledge resources efficiently. Meanwhile, the issue of sustainability has become critical in recent years due to global concern on the impact of business on resources, the environment, and society. Traditionally, sustainability is articulated as the triple-bottom-line framework of economic, environmental, and social dimensions [5]. In the current era of the 4th industrial revolution, the internet of things, the shared economy, and the implementation of artificial intelligence has started to affect firms, supply chains, and the whole ecosystem. Business sustainability and continuity, risk management, and solutions are relying more and more on collaboration through flexible, dynamic, and open platforms. This brings new themes to the concept of sustainability in terms of social requirements, culture creation, policy support, a green economy, responsibility, and technological advancement.

The scale of business nowadays ranges from individual firms to supply chains consisting of hierarchical management, to ecosystems featuring collective investments and interactive management [6]. The literature on ecosystems indicates the presence of three streams [6]. The first stream is similar to early studies on business ecosystems, viewing business ecosystems as communities of organizations, institutions, and individuals, which is beyond the boundary of a single industry [7,8]. This could explain how an industry grows through expansion from existing collaboration to convergence and renewal phases [7]. The second stream, known as an innovation ecosystem, focuses on knowledge activities through diverse collaboration. The third stream explores platforms which are provided by organizations or governments for value creation and knowledge sharing. Open innovation activities that are initiated by firms, such as open-source technology development and standardization, belong to this research domain [6]. Previosly, large firms created products and value with internal resources protected by IP, which was known as closed innovation, whereas an open innovation economy is more evidential in SMEs and start-ups through knowledge sharing [2,4]. Social innovation provides technology and knowledge, which deliver social value to society. It is believed that the emergence of a shared economy is the result of open innovation and social innovation, in which social and technology requirements are linked together [9]. To explore

the interactions between different economic patterns, Yun proposed a dynamic model, suggesting a lifecycle beginning with an open innovation economy via a closed innovation economy, which included industry convergence, technology licensing, and M&As, to a social innovation economy via combining technology with social values and then back to the open innovation economy again to seek new technologies and markets [2].

Alongside open innovation are the triple-helix, quadruple-helix, and quintuple-helix theories, which identify connections among various stakeholders. The triple-helix theory demonstrates a non-linear innovation model through university, industry, and government policy interactions [10]. While each helix develops internally, they also exchange knowledge, products, and services [11]. It is argued that the triple-helix model is implemented more in Western countries, highlighting top-down governments and institutional policies [11]. The quadruple-helix theory further introduces the role of civil society, media, and the culture-based public. It combines top-down policies and bottom-up grassroots initiatives, co-creating knowledge and value, which can be applied to both developed and developing economies [12,13]. Innovative culture can also be formed through media [13]. The latest theory, the quintuple-helix model, extends the previous frameworks by highlighting the role of the environment and thus links the concepts of innovation and ecological sustainability together [13].

Based on current knowledge, business, and society trends, our paper aims to answer the following question: "How can sustainability be achieved through open innovation in the current 4th industrial revolution"? We conducted a literature review on open innovation from the perspectives of industries, governments, universities, and society, in addition to open innovation micro- and macro-dynamics. Based on this analysis, a conceptual framework was generated, demonstrating the possibility of supporting sustainability through open innovation activities. We have collected special issue papers which could meet the concept model "micro- and macro-dynamics of open innovation with a quadruple-helix model". As the editorial paper, we have also summarized papers published in this special issue, addressing key research agendas in open innovation and sustainability in the context of the 4th industrial revolution.

2. Quadruple-Helix

2.1. Industries Continuously Adopting Open Innovation Practices

Early literature explores large firms depending on internal R&D to create new products and services; this is defined as closed innovation [4,14]. However, externally generated ideas can be a major resource for innovation in many business sectors, as in the case of open innovation which breaks the traditional organizational boundaries [4]. Open innovation can be categorized into inbound and outbound activities [15]. Inbound, or outside-in, practices refer to the knowledge flow into the firm. Examples include consumer co-creation, information networking, university research grants, contracting with external R&D service providers, IP in-licensing, and crowdsourcing. Outbound, or inside-out, innovation refers to knowledge moving out of the firm through selling of market-ready products, participation in public standardization, corporate business incubation and venturing, IP out-licensing and patent selling, and spinoffs. Inside-out technology exploitation and outside-in technology exploration can create value for companies [16]. In addition, the coupled process combining features of inside-out and outside-in innovation can be achieved through joint ventures, cooperation, and alliances [17].

A survey of large firms in Europe and the USA suggests that open innovation is widely practiced, with customer co-creation, informal networking, and university grants being leading inbound practices, whereas most outbound practices are joint ventures, the sale of market-ready products, and standardization [15]. Empirical investigations and case studies suggest that large firms conduct open approaches to access external knowledge, form collaborations, and develop new products. Dodgson et al. (2006) took P&G's "connect and development" strategy as an example to discuss the impact of open innovation and found that P&G's technology entrepreneur network has the ability to conduct data mining, run simulations and modeling, and create rapid virtual prototyping technology, thus saving R&D time [18]. Regarding the computer aided design (CAD)

system, virtual prototyping technology evaluates suitable materials from sustainability perspectives in P&G. With the increasing application of AI in internet-based communication networks, the innovation process customizes searches and matches user interests [18]. Another company, General Electronics (GE), also adopts open collaboration as a strong platform to collaborate with start-ups and researchers, which results in new, sustainable products [19]. The open innovation practice used by Google is regarded as dynamic, continuous innovation, which acquires external technologies from universities, industries, research institutions, and venture capital groups in Silicon Valley. The open innovation strategy is an extension of Google's internal culture with empowerment, virtual cross-functional, and cross-product team collaboration [20].

While open innovation is easier to carry out in large firms, SMEs with resource constraints may have difficulty exchanging external technologies [21]. Though alliances, co-operation, and networking are common phenomena in SMEs, they are more considered as having access to the downstream market rather than upstream technology development [22]. Through investigating the success of open innovation in South Korea, it was found that intermediaries such as service providers can help SMEs to build trust between network members and reduce barriers to innovation [23]. It is also suggested that policy support can facilitate the innovation capabilities of SMEs [23]. Specifically, the governments of emerging economies can link large firms and SMEs together [24]. In fact, SMEs are playing an active role globally, by providing competitive advantages in specialized knowledge and intellectual property [17].

2.2. The Role of Governments in Moving toward Permissionless Open Innovation

While open innovation mainly takes place in industries, it can be promoted by policies. To start with, governments and public sectors can initiate open innovation to manage public-related projects and services effectively. Studies on leading countries, including the USA, Australia, and Singapore, indicate that policies at the national level can facilitate innovative atmospheres through networks and online platforms [25]. Government-led and community-led networks are two types of collaboration in management of the public sector [26]. E-government websites, community-led innovation, and voluntary events are recognized as good innovative practices to support American environmental management and police services [25]. Online initiatives, collaborative problem-solving events, public–private collaborations, public services, social networking, crowdsourcing, eCitizen portals, and government–university collaborations are all approaches of governmental open innovation [25].

Apart from conducting open innovation in public service management, governments can be innovation catalysts, facilitating an innovation ecosystem on national and regional levels [26]. According to Faber et al. (2008), there are three roles of the government in innovation systems. Firstly, as a broker, a government can issue frameworks and public infrastructure to bring different actors of innovation together. Examples include Intellectual Property Right (IPR) sharing and technology transactions [27]. Secondly, governments can stimulate demand and create markets, for instance, through building commercialization channels, industry clusters, incubators, and strategic alliances between high-tech companies and emerging industries [27]. Thirdly, governments can influence knowledge using fiscal policies, S&T policies, and capital markets [27].

In emerging countries, latecomers can learn and utilize external R&D resources through acquisition, joint ventures, and collaborations [28]. Regulation has a strong impact on the technology catching-up process [29]. Surveys regarding the practices of Chinese companies suggest that, although closed innovation remains popular, there is a growing trend of open innovation since 2000 due to the national government's encouragement for firms to go global [30].With science and technology (S&T) and economic policy support in China, open market environments and innovation climates are gradually formed, featuring more open, active, and aggressive ways of external knowledge sourcing [30]. Through studies in Changzhou city, China, an area originally lacking universities and leading firms, it was found that the government can play a centralized role in the creation of knowledge resources by establishing universities and research institutions, bridging them with industries, and then stepping down as a facilitator to provide sharing platforms when the

ecosystem matures [31].Thus, the role of the government changes throughout different stages of ecosystem innovation [31]. While an open innovation framework is mainly based on focal firms which provide platforms for collaboration, known as "supply-driven", it is argued that the government can also create open platforms and stimulate demand, known as "demand/customer-driven" innovation [24]. This can be important for emerging markets and new industries, where there are limited local business organizations with innovation capabilities and incentives [24].

While governments support new industries with platforms and policies, they also play an essential role in the sustainability of innovation. Issues, such as how innovation can avoid harming people and the environment, can be linked with a combination of soft and hard legal regulations [32]. The theme of responsible innovation, which takes long-term acceptability, sustainability, and societal desirability into account regarding the innovation process, also emerged recently [33]. The dimension of anticipation (e.g., risk analysis, public engagement, technology assessment), reflexivity (e.g., institutional reflexivity, standardization), inclusion (e.g., engagement with stakeholders), and responsiveness (e.g., responsiveness to new knowledge and changes) are identified as a conceptual framework of responsible innovation [34]. However, so far, responsible innovation has been explored more in developed countries and less in emerging economies [35].

2.3. The New Role of Universities as Proactive Collaboration Agencies

The role of universities changes dynamically along with the innovation modes. Under the context of Mode 1, universities serves the traditional role of education and fundamental research, without involvement in applications [36]. Most university–industry partnerships are led by government projects with public policies [37]. As for Mode 2, knowledge transfer and R&D commercialization are highlighted with particular applications and societal needs [36]. Typical knowledge transfer channels include publication, conferences and meetings, contract research, co-supervising PhD students, consulting, and collaborative research [38]. Still, the approaches emphasize linear communalization [39]. Lately, with the new concept of Mode 3, non-linear simultaneous innovation is observed between universities and industries [40]. The triple-helix (Etzkowitz and Leydesdorff, 2000) theory further points out the interaction among universities, governments, and industries. Universities are engaging proactively in open networks and interactive innovation, rather than passively creating scientific knowledge and instrumentation infrastructure like in the past [10,41]. There are also increasingly more research joint ventures among universities and industries for knowledge creation and exchange [42].

While linear innovation of technology transfer is thoroughly studied, the literature on university engagement focuses mainly on motivation, personal characteristics, and forms of engagement [39]. The engagement of universities in innovation is categorized as a formal way of out-licensing university patents, spin-offs, collaborative R&D, and an informal way of communication [43]. The patterns are further identified as joint research, contract research, staff mobility, and training [44]. Based on a literature review, Perkmann and Walsh (2007) proposed a framework to distinguish the university–industry relationship from IP transfer toward dynamic information and social links. High-relational involvement focuses on specific projects and outputs, whereas typical low-relational involvement involves licensing of university IP [41]. Science-based business sectors such as pharmaceuticals rely on university–industry research partnerships for breakthroughs, whereas research services, where industries are clients of universities, are preferred by business sectors highlighting incremental improvement [41]. In particular, consulting and contract research are more effective at the later stages of the innovation cycle for product differentiation and improvement [45].

The concept of an entrepreneurial university is proposed to foster the commercialization of academic results through patent application, out-licensing, and the establishment of new companies [46]. Universities can act in an intermediary role, bringing producers and users of knowledge together [47], which creates trust and committed relationships [39,47]. Exploratory studies also uncovered the new role of universities as trusted intermediaries or open innovation hubs [37]. Various interaction mechanisms have been identified in the university–industry collaboration in the form of radical innovation and incremental changes [41].

2.4. Societal Engagement with the Shared Economy

The involvement of customers and society in innovation have been studied in the literature regarding crowdsourcing. For the public sectors, governments can use online platforms to invite citizens to provide ideas [25]. Crowdsourcing is used by industries to outsource projects to a network of people through an open call [48]. It contributes to firms' upstream decision-making related to product development and downstream activities to approach consumers [49]. Crowdsourcing previously linked specific projects with a temporary base, but now also helps with business continuity [49,50]. Products and services can focus on customers earlier and improve speed to market by involving crowds in the innovation ecosystem [51]. Thus, crowdsourcing enriches new project development and commercialization with flexibility, speed, dynamism, and scalability [49].

Customers are no longer passive buyers, but are involved in product development [52,53]. Customer-driven open innovation platforms can be formed by governments, especially for new industries [24]. With technology advancements, e-commerce, and information systems, shared economies have become a new business model [54]. Uber, Airbnb, and bicycle-sharing systems are just a few examples demonstrating exchange of products and services among citizens and businesses [54]. Social media, as a tool to facilitate R&D and commercialization, is used by industries to capture consumers' value and generate interactive communication [55]. It can also include users for commercialization and brand image promotion [55]. Through multiple case studies, Mount and Martinez [55] explore the dynamics of social media across the innovation funnel, suggesting that social media becomes more integrated within the innovation system [55].

On a broad level, society, or social responsibility, is among the essential pillars of sustainability. The issue of society is revealed in the quadruple-helix theory, as civil society, including media, users, agencies, and culture can drive the innovation process [56]. For example, with global concern on environmental impact, the quadruple-helix model can be applied to industries, governments, universities and society (consumers and citizens) to design strategies to achieve green economy [57]. Social innovation, articulated in recent years, refers to innovative activities which are motivated by social needs and serve society [58]. Along with it are social enterprises which bridge traditionally private commercial and non-for-profit organizations, exchanging ideas and values for social and public need. The active role of culture, media, and society also brings new research agendas to sustainability and innovation.

3. Open Innovation Micro-Dynamics

Open innovation micro-dynamics are observed to be significantly scaled in reality. With good control of open innovation complexity, focal firms can gain new opportunities through evolutionary changes (Figure 2). Such examples are the Apple smart phone, the micro soft (MS) cloud service system, the Burro battery, and the Megajen implant [59]. However, failure to control the complexity along with the open innovation, like in the cases of the Galaxy Note 7 battery explosion and the Medison M&A by Samsung, can hugely harm the firm [60]. There are many studies analyzing open innovation micro-dynamics, from aspects of entrepreneurial orientation, environmental uncertainty, SEMs' employee creativity, the role of dynamic capabilities as a business model, and open markets [61–64].

Open principles in new business models of information systems, learning patterns in dynamic technological system lifecycles, triggers of collaborative innovation in online user communities, and the transformation from design thinking to artistic thinking are also emerging themes of open innovation micro-dynamics [64–67].

In uncertain markets, new metrics can help companies to play poker as well as chess by managing open innovation [68]. Specifically, databases, case studies, and theoretical research have revealed that SMEs require motivations of open innovation with good control of the increasing complexity from various aspects [17,23,69,70]. Demand articulation in the open innovation paradigm, moving beyond fusion toward IoT by means of open innovation and learning mode in the 4th industrial revolution, are examples of approaches to smooth open innovation micro-dynamics [71–73].

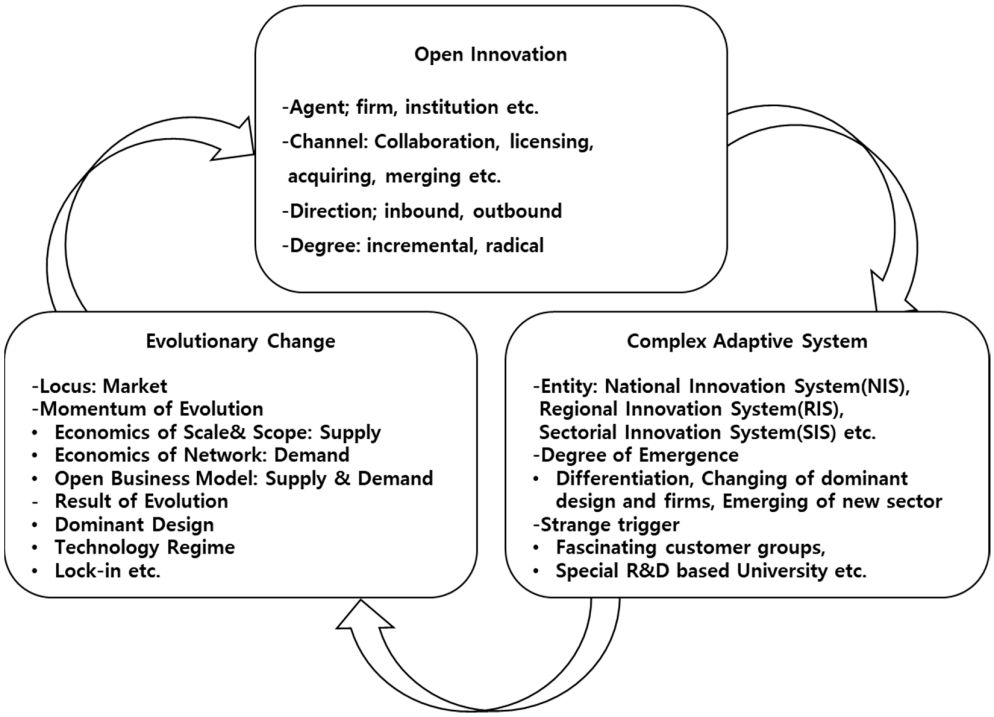

Figure 2. Open innovation micro-dynamics. Source: [1].

4. Open Innovation Macro-Dynamics

Open innovation in national innovation system (NIS) can motivate the economic growth by increasing open innovation macro-dynamics. Though open innovation macro-dynamics may not be seen, they can be appreciated, captured, and analyzed [74]. Good circling among the social open innovation economy, the market open innovation economy, and the closed open innovation economy can motivate economy growth in a sustainable way and thus conquer the growth limits of capitalism (Figure 3) [2,75].

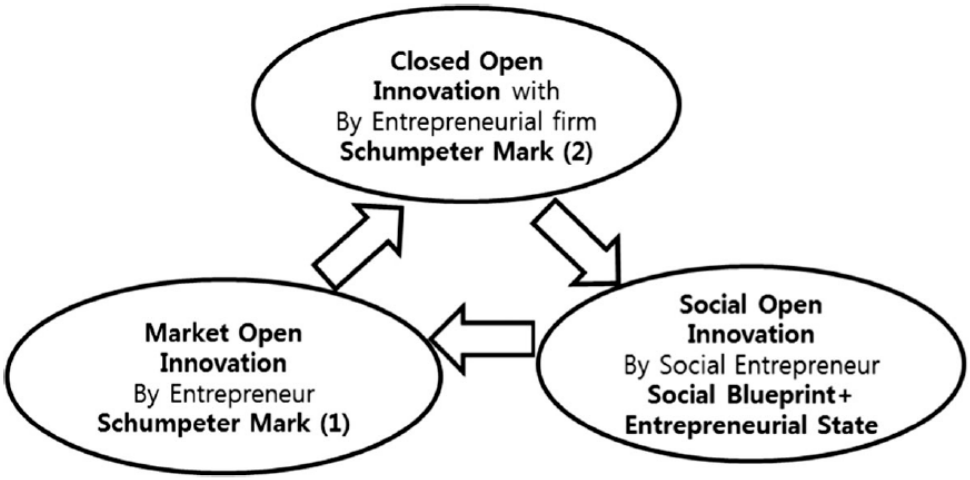

Figure 3. Open innovation macro-dynamics. Source: [3].

Specifically, the dynamic balance between the three open innovation sub-economies, which is opposed to either a too high or a too low balance, is required to reach high quantitative and qualitative economy growth. This is because economic systems, institutions, and peculiarities of

national culture may influence largely on firms' behaviors in terms of their engagement in open innovation practices [76].

Historical and parallel reviews on open innovation patterns at national, sectorial, and regional innovation system levels show high relation between open innovation macro-dynamics and economy growth rate [77–80]. Therefore, as the momentum for open innovation macro-dynamics weakens, the world may change dramatically with the number of entrepreneurs declining, meaning no synergy of innovation systems between open innovation and triple-helix in the 4th industrial revolution would be achieved [81–83].

Sustainable development of smart cities toward comprehensive and human-centered smartness is another physical example of open innovation macro-dynamics in the design of knowledge and innovation in the public space [84–87].

5. Toward a Framework of Sustainability through Open Innovation

Through open innovation, the content of sustainability is enriched. On one hand, the triple-bottom-line of economic, social, and environmental sustainability remains fundamental, as governments, industries and society highlight economic, legal, ethical, and philanthropic responsibilities. On the other hand, more issues, such as knowledge creation, user engagement, policy support, and the shared economy, lead sustainability in a non-linear, dynamic way. Innovation now requires co-creation and collaboration among various stakeholders to motivate the open innovation micro- and macro-dynamics.

From our literature review and analysis, it can be seen that industries now continuously adopt open innovation platforms for knowledge creation, sharing, and commercialization. Open innovation forms are moving from inbound and outbound activities toward coupled processes. While leading large firms have resources to exchange, SMEs can demonstrate specialized expertise on open platforms. With government facilitation, collaboration among companies can result in knowledge, product, and economic sustainability. Governments previously focused on regulation control and standardization, however, this role is gradually moving toward facilitating collaboration among universities, industries, and society. In emerging markets with limited innovation capabilities, governments can help to create knowledge and stimulate demand, thus promoting new industries. This demonstrates a potential for social and economic sustainability. Furthermore, responsible innovation can be initiated by governments to achieve business ethics and ecological sustainability. The traditional function of universities to advance education and scientific research is being replaced by knowledge transfer, and now by proactive co-innovation, due to the concept of entrepreneurial universities and trusted intermediaries. Customer involvement, social innovation, and social media implementation also contribute to the diversity, flexibility, scalability, openness, and dynamics of innovation in a sustainable way. Shared economies, creative culture, and smart cities are other themes in the current era of the 4th industrial revolution, especially at the national and regional levels. To summarize our analysis, a conceptual framework is proposed in Figure 4, which addresses the interactive roles of industry, government, university, and society in terms of knowledge, product/service, ecological, responsible, social, and cultural dimensions of sustainability from micro- and macro-systems.

Open innovation provides alternatives for products, services, and business model innovation from the traditional closed innovation either at the firm or the supply-chain level. In fact, the concept of the business ecosystem, combining direct and indirect collaboration, features diversity, dynamics and interaction of open innovation. Table 1 addresses the changes of innovation across different levels of individual firm, supply-chain, and business ecosystems. At the organizational level, closed innovation takes place with internal R&D resources. Industries, universities, governments, and societies are static and separated with limited interaction. At the supply-chain level, both formal closed innovations based on partnerships and informal open innovation are observed from industry and government perspectives. The business ecosystem expanded innovation activities from formal supply-chain partners toward indirect collaboration in various forms. Apart from industry initiation, universities, governments, and societies are actively contributing to value co-creation. Thus,

sustainability can be achieved through the joint effort of resource and knowledge sharing, aiming for a long-term impact on the economy, the environment, and society.

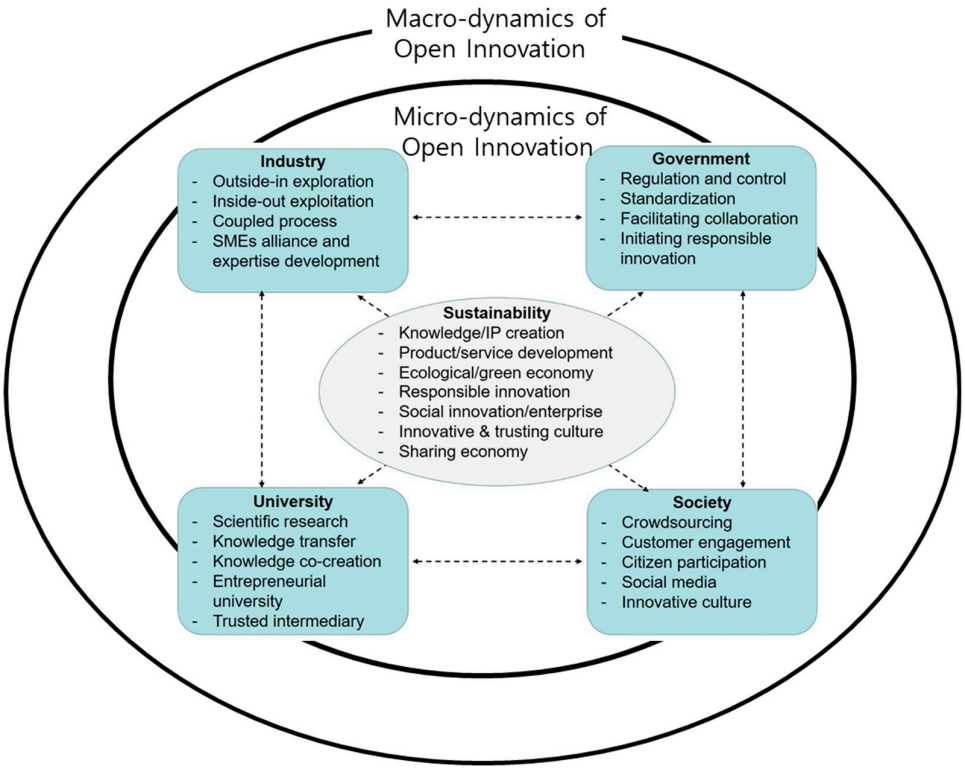

Figure 4. The roles of the quadruple-helix model for open innovation micro- and macro-dynamics.

Table 1. Features of closed and open innovation on different levels.

Role	Organization	Supply Chain	Business Ecosystem
Industry	Closed innovation: In-house R&D in large firms	Closed innovation: Joint R&D activities between supply chain partners, lean/agile supply chain Open innovation: Open platform for crowdsourcing, IP in-licensing, joint venture activities	Open innovation: Strategic alliance of large firms and SMEs informal network, various knowledge sharing, and collaboration
University	Closed innovation: Education and S&T research	Closed innovation: Technology transfer from university of industry based on specific projects	Open innovation: Active simultaneous co-creation with industry
Government	Closed innovation: Policy making	Closed innovation: Standardization, collaboration on specific projects Open innovation: Open platform to obtain ideas and solutions	Open innovation: Facilitating by infrastructure, framework and indirect support, broad collaboration, initiating responsible innovation

Society	Closed innovation: Passive users	Closed innovation: Customer need and relationship management	Open innovation: Customer engagement, resource and demand sharing, co-creation of product and service

Open innovation involves various organizations and entities co-creating knowledge together across different levels. The phenomenon should be regarded as a dynamic process rather than static behavior. The relationship of industries, governments, universities, and society demonstrates interaction and co-evolution on the macro-dynamics level. This is consistent with Yun's model of the open innovation economy system [2]. With a classic theory basis from Maxi and Schumpeter, and recent findings from Drucker, Rifkin, and Piketty, the open innovation economy system (OIES) model aims to articulate a sustainable approach to conquer the growth limits of capitalism [2]. There are three stages within the lifecycle of OIES, namely, the open innovation economy featured by SMEs and start-ups, the closed innovation economy featured by large firms and internal R&D, and the social innovation economy. It is believed that many open innovation activities start with SMEs and individual entrepreneurs who are active to learn and share knowledge together, forming new industries and business models in a flexible, collective way. With the scale of business expansion, a closed economy can be formed, as firms gradually build internal resources and capabilities, relying on internal R&D and protecting their IP. This can be seen in leading large firms, who create IPs and values, transferring knowledge and technology to markets for economic growth. A social innovation economy emerges later on, as firms should focus not only on financial growth, but also on the impact on the environment and society. This can be traced back to the concept of CSR. However, more than CSR, societal innovation economies involve a diversity of social enterprises, users, and individuals who create and exchange resources to meet social requirements. These three macro-level innovation economies are not separated, but connected together with interactive mechanisms. For instance, through M&A and collaboration, SMEs can become large firms, transferring from an open innovation economy to a closed innovation economy [2,3]. Alternatively, as large firms break boundaries by launching open platforms, closed innovation economies can also transfer toward open innovation economies. The mutual transfer of social innovation to both open and closed innovation economies is also achievable, as firms combine technology and society and social enterprises seek strategies to connect social values with the market [2]. In fact, the prosperity of a shared economy illustrates possible interactive relations between firms, individuals, and society, aiming for economic and social sustainability in an open collective way. Other macro-dynamic factors, such as the architectural design of universities and research campuses, manufacturing systems, and districts, can also influence the degree of open innovation with regard to tacit knowledge in the society (Yun et al., 2018).

On the micro-level, it can be seen that both large firms and SMEs are engaging more with open innovation. User participation, social innovation, crowdsourcing, and strategic alliance are popular forms of innovation activities. With environmental, industry sectorial, and supply and demand changes, business models on the micro-level also experience dynamic changes. According to Yun et al., such processed can be divided into stages of open innovation, complex adaptive systems, and evolutionary change (OCE) [1]. The OCE model is developed from five groups of studies, which include the resource-based view, the transaction cost theory, the history-friendly model, the dynamic capability theory, and evolutionary theories of business activity. Existing theories have addressed important issues such as capability and cost reduction, but not in terms of the real triggers and the effects of dynamic capabilities. Thus, with the new conceptual model, solutions are given, which can be further validated in the smartphone industry [1]. The OCE model starts with open innovation on the firm level, as firms absorb external technology resources and respond to market requirements. Then, the system transfers toward a complex adaptive system, where a diversity of stakeholders including firms, customers, and service agents are actively involved, interacting with national innovation systems, regional innovation systems, sectorial innovation systems, and the innovation systems of firms. Different triggers can result in new R&D capability and technology development.

Political intervention is also considered during this stage. Moving on to the third stage, evolutionary changes in the OCE model and the coevolution of industries, technologies, universities, and governments can happen, which also results in technology and market evolution. With positive feedback on both supply and customer sides, open business models can reach self-supply in a sustainable way. In fact, the dynamic model on the micro-level also shows differences along with the industry lifecycle. In particular, in the early stages of the converted industry sector, business models can be more important than technology [88]. However, for the emerging sector, the early stage shows the predominance of technology over the business model [88]. For a mature industry, both factors should be highlighted [88]. Therefore, the OCE model provides a solution for firms to realize their positions at the industry lifecycle and develop sustainable growth strategies through co-evolution and open innovation.

6. Editorial

Following the above discussion and identification of emerging themes of sustainability through open innovation, our special issue attempts to answer in particular the question of how to respond to the 4th industrial revolution, with open innovation and cyber-physics, from manufacturing to the service industry, which is the theme of the Society of Open Innovation: Technology, Market, and Complexity (SOItmC) 2018 annual conference. It seeks to collect theoretical and empirical studies on open innovation management, open innovation economy, open business models, open service innovation, open cyber-physics, and other related issues. 38 papers published in this special issue are from different perspectives, yet they all aim to contribute to the theory of innovation and sustainability, providing new views on how the sustainability of the economy, the environment, and society in the 4th industrial revolution is possible at the macro- and micro-levels.

In this special issue, Paper One analyzes the role of international entrepreneurial orientation in successful internationalization from the network capability perspective with the open innovation concept, which focuses one integrating universities and businesses in the digital age [89]. Paper Two examines the effect of narcissism on the performance of a firm, in connection with the scope of coaching in the context of organizational change [90]. Paper Three studies the effect of open innovation on the value of technology and technology transfer in Korean automotive, robot, and aviation industries from the perspective of inclusive open innovation [91]. Paper Four is a systematic literature review of lean driven sustainability. Paper Five explores intellectual property management and network strategies which influence open technological innovation from the aspect of open innovation cost and benefits [60]. Paper Six analyzes Chinese-listed companies which are shifting from short-term goals of maximizing profits to long-term, sustainable environmental, social, and governance (ESG) goals. Paper Seven analyzes the effect of social entrepreneurs on the performance of Korean social enterprises from the mediating effect of innovativeness to the implementation of the open innovation concept in social business [92]. Paper Eight studies the structural relationship and influence between open innovation capacities and performance from the perspective of open innovation micro-dynamics directly. Paper Nine analyzes the regional innovation system as s complex adaptive system with virtues of variety in regional innovation systems and entrepreneurial ecosystems [79]. Paper Ten measures the inclusive growth of China's coastal regions.

Paper Eleven studies the critical success factors of a design start-up business, not by fusion but using an open innovation approach [72]. Paper Twelve analyzes a machine-learning approach to the residential relocation distance of households in the Seoul Metropolitan region, from the perspective of research ethics education in Korea for overcoming culture and value system differences [93]. Paper Thirteen is a research on the characteristics of SMEs preferring cooperative R&D support with the idea of open innovation micro- and macro-dynamics. Paper Fourteen studies the role of community-led governance in innovation diffusion [94]. Paper Fifteen studies factors which affect pricing in patent licensing contracts in the biopharmaceutical industry by using the valuation method of loyalty data in the life-science area [95]. Paper Sixteen is about the moderating effect of network structure on the performance of SMEs, along with the relationship of R&D expenses and turnover and number of listed companies in all industrial fields [96]. Paper Seventeen studies platform adoption factors in the

internet industry with relation to customer involvement through social media [97]. Paper Eighteen explores the innovation system of China's animation industry from an open innovation macro-dynamics perspective. Paper Nineteen builds up an open innovation model of coaching interactions of organizations for sustainable performance within the lifecycle, with relation to the role of innovation capabilities on total quality management (TQM) practices [98]. Paper Twenty studies the effect of food tourism behavior on food festival visitors' revisit intention, with relation to the effect of Hallyu on tourism in Korea [99].

Paper Twenty-one studies technology in innovation systems from an ecosystem innovation perspective, with relation to technology convergence [100]. Paper Twenty-two is about fuzzy analytic hierarchy process (AHP), data envelopment analysis (DEA), and managerial analysis for supplier selection and development from an open innovation perspective [101]. Paper Twenty-three is about promoting the development of enterprise niches through a case study on China's organizational ambidexterity from the perspective of a platform business eco-model evolution [102]. Paper Twenty-four is about the green governance of open innovation with the philosophy of collectivism and individualism of open innovation [103]. Paper Twenty-five is about the impact of construction of IT technology convergence innovation on business performance from the perspective of a global innovation network [104]. Paper Twenty-six is about the relationship between the corporate sustainability and green innovation from the perspective of systematic thinking [105]. Paper Twenty-seven is a predictive analytics approach to improve and sustain college students' non-cognitive skill and their education outcomes to develop a student-customized creative education model based on open innovation [106]. Paper Twenty-eight is about enhancing road network resilience by considering performance loss and asset values. Paper Twenty-nine is about architectural open innovation of tacit knowledge with open innovation macro- and micro-dynamics. Paper Thirty is about the impact of technology habitual domains on ambidextrous innovation from the perspectives of open innovation and business models [107].

Paper Thirty-One is about citizenship motivation of public service. Paper Thirty-Two is about the effects of maturity of project portfolio management and business alignment on project management office (PMO) efficiency, which has a relationship with the CEO characteristics [108]. Paper Thirty-three is about the anti-aging cosmeceuticals in Korea and open innovation in the 4th industrial revolution, from the perspective of open innovation micro-dynamics. Paper Thirty-four explores the relationship between green governance and international business strategies from the aspect of entrepreneurial cyclical dynamics of open innovation. Paper Thirty-five searches for the various effects of subprograms in official development assistance on human development to conquer the growth limits of capitalism in a new, creative way [75]. Paper Thirty-six evaluates the long-term stability and the impact of remittances and development aid on sustainable economic growth in developing countries. Paper Thirty-seven is about the optimal emission decisions of sustainable production with innovation baseline credit regulations from an open innovation macro-dynamics perspective. Paper Thirty-eight is about paternalistic leadership and innovative behavior from an open innovation micro-dynamics perspective.

7. Conclusions, Implications, and Future Research Agenda

7.1. Implication

This paper has proposed the conceptual model of "open innovation macro- and micro-dynamics with a quadruple-helix model" as the way to achieve sustainability of the economy, society, and the environment in the 4th industrial revolution. The model is built up from an extensive literature review on open innovation, micro-dynamics, and macro-dynamics.

Meanwhile, it has summarized 38 papers published in this special issue as the editorial paper of the special issue "Sustainability of Economy, Society, and Environment in the 4th Industrial Revolution" from the perspective of the concept model of open innovation macro- and micro-dynamics with quadric-helices.

7.2. Future Research Agenda

As for the future research, firstly, from the open innovation micro-dynamic perspective, this conceptual model needs to be further validated. Case studies from diverse industries, regions, and nations can further develop and enrich the "open innovation micro-dynamics model with quadric-helices".

Secondly, we should further identify the role of quadric-helices regarding the open innovation macro-dynamics from more case studies of diverse nations, regions, and sectors.

Thirdly, the concept model of open innovation macro- and micro-dynamics of quadric-helices will be developed by diverse concrete studies, so as to conquer the growth limits of capitalism.

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